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eology and Ground-
/ater Resources of
itsap County
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EOLOGICAL SURVEY WATER-SUPPLY PAPER 1413

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volcanic rocks which rise as an "island" above the surrounding plate surface to a maximum altitude of 1,761 feet. Their individual hi are separated by steep-walled canyons which have been eroded depths as great as 1,000 feet.

AREA SUBDIVISIONS

Kitsap County includes five major upland plateau areas (fig. 2 For convenience of reference in this report, all these except Bai bridge Island have been given locational designations. The southe upland lies south of Port Orchard Bay and of its southwestwa continuation, the Gorst Creek-Union River trough. The weste upland, the largest in the county, lies west of Port Orchard Ba Dyes Inlet, Liberty Bay, and the Lofall-Poulsbo trough. The centr upland forms the Manette Peninsula. The northern upland occupi the area east and north of the Lofall-Poulsbo trough. Bainbrid Island is an area isolated from the present mainland, east of t Manette Peninsula.

SOUTHERN UPLAND

The southern upland is a large irregular-shaped rolling upland ar that comprises about 125 square miles. Its surface ranges genera in altitude from 300 to 450 feet but rises to a maximum of 525 fe Its chief land forms are broad, flat-topped hills and ridges.

The area is drained by many small streams, which are fed springs whose flows are supplemented by direct surface runoff duri the winter and spring months. Several of these streams occu valleys formed during a preglacial period of erosion. Burley Cree a southward-flowing stream in the southern part of the upland, about 4 miles long and discharges into Burley Lagoon, a submari continuation of its former valley. Olalla Creek, which occupi another former drainage channel in the southeast part of the uplan flows south and east and discharges into Colvos Passage. Blackjac Creek flows northward for about 7 miles in the north-central part o the upland and discharges into Port Orchard Bay. Other stream on the upland are smaller and occupy canyons and gullies cut sinc the glaciation of the region.

The southern upland contains several lakes and a large number o ponds. The largest, Long Lake, is in the east-central part of th upland and occupies part of a preglacial channel. Other lakes an ponds are above the regional water table and occupy depressions i the impermeable cover of glacial till that mantles most of the are

WESTERN UPLAND

The western upland includes the whole western part of the county an area of about 145 square miles of which 20 is in the Blue Hills

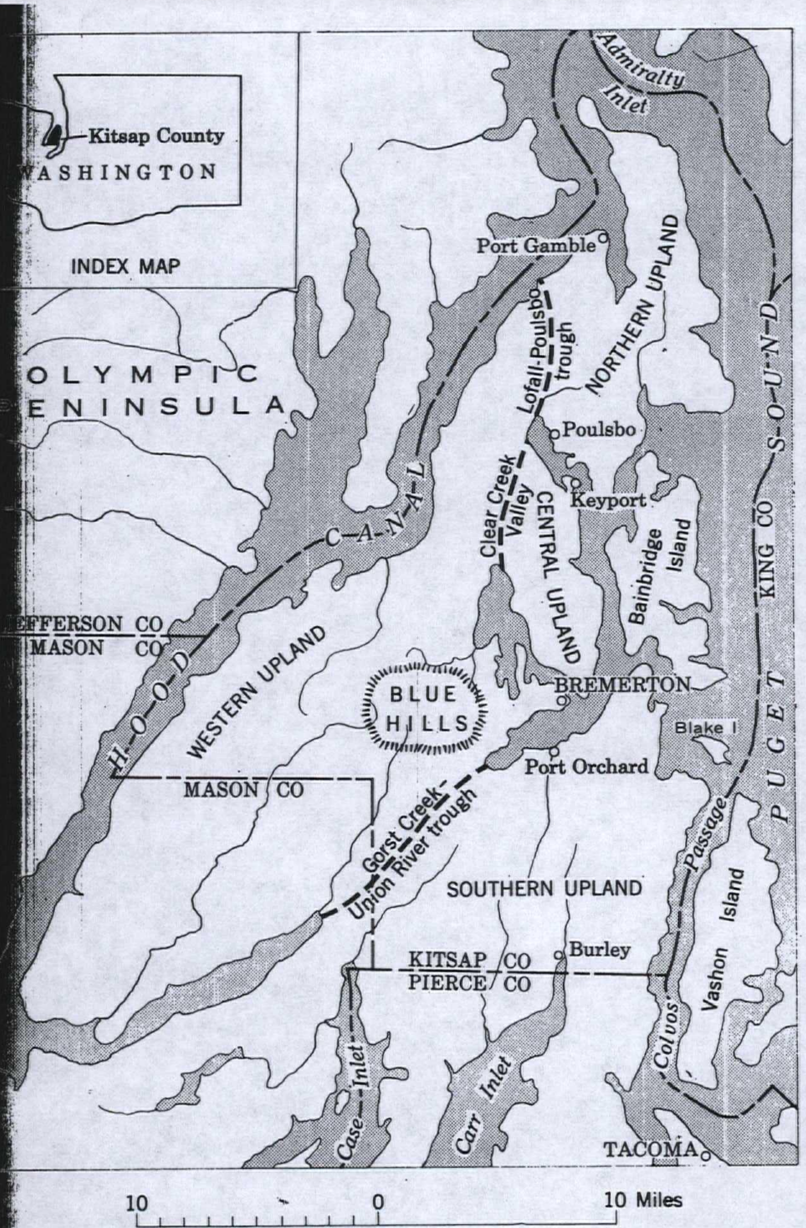


FIGURE 2.—Map showing the major upland plateaus of Kitsap County, Wash.

Excluding this mountainous area, the altitude of the surface genera
ranges from 300 to 600 feet but has a maximum of about 740 fe
the land forms are similar to those on the southern upland.

Drainage is primarily by short streams that discharge into Ho
Canal. Most of these streams occupy steep, narrow postglac
canyons and gullies.

The western upland is separated from the southern upland by
former glacial-outwash channel which connects Hood Canal wi
Port Orchard Bay. That trough is now drained by northeastwa
flowing Gorst Creek and the southwestward-flowing Union Riv

CENTRAL UPLAND

The central upland comprises the Manette Peninsula; it is separat
from the western upland by the southwest-trending Clear Cre
valley. The central upland includes an area of about 30 squ
miles and has a maximum altitude of about 480 feet. The upland
drained by short streams that discharge into the surrounding branc
of Puget Sound.

NORTHERN UPLAND

The northern upland includes an area of about 65 square mi
It attains a maximum altitude of about 520 feet but most of the l
area ranges from 200 to 400 feet. It is separated from the west
upland by a narrow drainage channel which extends from Lofal
Liberty Bay at Poulsbo. Drainage of this area is similar to tha
the central upland.

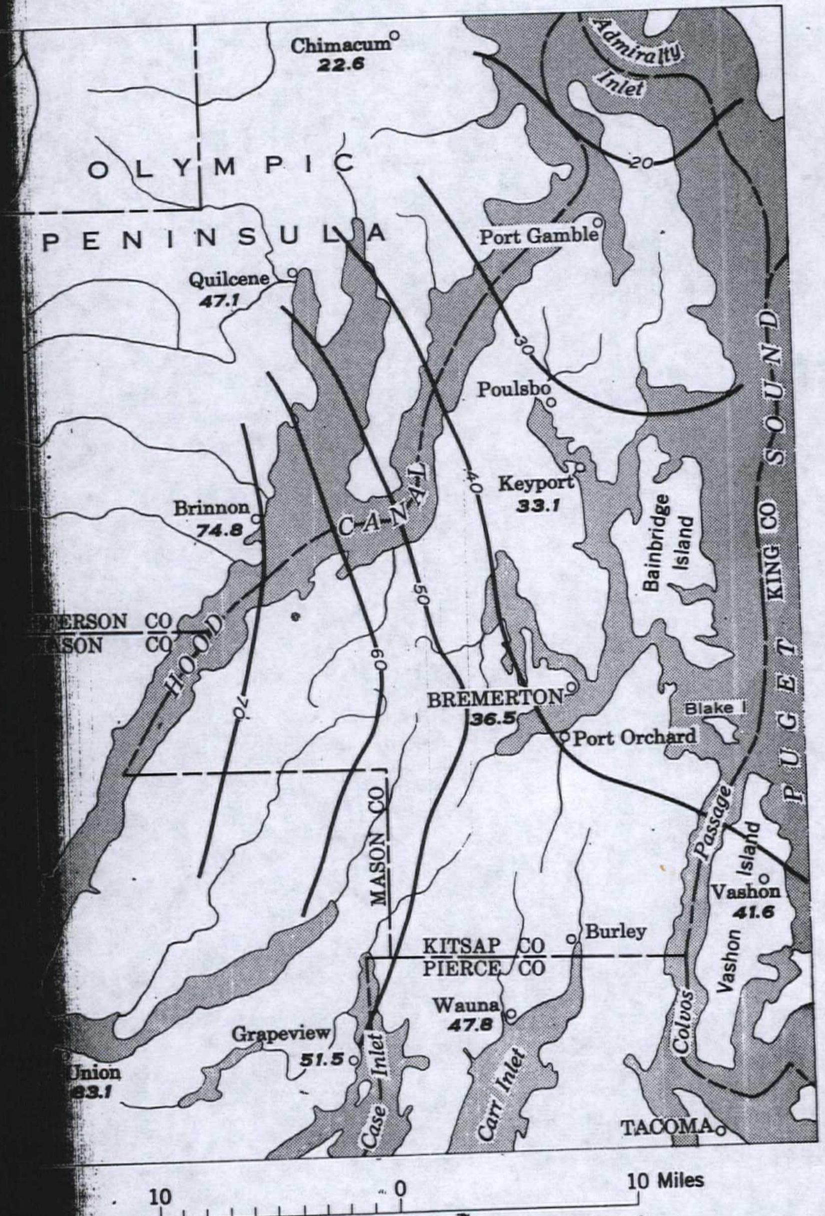
BAINBRIDGE ISLAND

Bainbridge Island is a roughly rectangular island about 10½ m
long and 3½ miles wide east of the central upland. Its area is ab
26 square miles. The hilltop just east of Fort Ward, with an altitu
of 425 feet, is the highest point on the island. The altitude of m
of the island is 200 to 300 feet.

The principal land forms are broad glacially smoothed hills. Dra
age is by small, short spring-fed streams. Several small ponds occu
depressions in the glacial till that mantles most of the island.

CLIMATE

Kitsap County has an equable, oceanic climate with generally m
temperatures and moderate to heavy precipitation. Precipitat
records of the U. S. Weather Bureau are available for five weat
stations in or adjacent to Kitsap County (figs. 3–5). Bremerton h
an average annual precipitation of 36.54 inches for a 53-year per
of record; Vashon, 41.62 inches for a 59-year period; Keyport, 33



Map showing location of past and present weather stations and the average annual precipi ation
ded at these stations. Isohyetal lines show approximate distribution of precipitation.

importance. The Puget Sound Naval Shipyard at Bremerton is now the chief source of employment in the county.

Agriculture is becoming increasingly important. Dairying and the raising of stock food account for the largest part of the area under cultivation. Increasing acreage of strawberries is an example of increasingly important intensified farming. The tourist business and the fishing industry supply a means of livelihood to another large group of people within the county.

VEGETATION

When Kitsap County was first settled in the middle of the 19th century it was mantled with a thick cover of vegetation. Douglas fir, cedar, and hemlock were the predominant varieties of trees. These forests, which were accessible from the numerous waterways of Puget Sound, gave rise to a large lumbering industry at an early date. In time the virgin forests were almost completely removed, though now they are being replaced by a crop of second-growth timber. The forested and other uncultivated areas are mantled by thick growths of salal, huckleberry, and fern.

GEOLOGY

GENERAL SIGNIFICANCE

Because the source, occurrence, and movement of ground water and the quantity and quality of ground water available are directly related to the geology of the region, a study of the geology is an important part of a ground-water investigation.

The Puget Sound trough, in its northern section, is a large structural basin in consolidated rocks of Tertiary and earlier age. It has been partly filled by unconsolidated deposits of clay, silt, sand, gravel, and glacial till. These unconsolidated sedimentary materials were deposited by water and ice during the Pleistocene glacial epoch (Ice Age), but in some low-lying areas Recent alluvial deposits underlie the surface. The upper materials of this fill, except the Recent deposits, were deposited by ice and glacial melt-water streams during the latest glaciation of the area (Vashon glaciation). During that glaciation, a large tongue of ice moved southward from British Columbia and Vancouver Island and partly filled the Puget Sound basin (Bretz, 1913, p. 17).

DESCRIPTION OF THE ROCK UNITS

TERTIARY ROCKS

VOLCANIC ROCKS

The oldest rocks that crop out in the county are the thick sequence of basaltic flows that underlie the Blue Hills area. Correlative volcanic rocks on Vancouver Island, British Columbia, were first described and named the Metchosin volcanics by Clapp (1909). They have since been described on the Kitsap and the Olympic Peninsulas in Washington by Weaver (1937). They are believed to be of Eocene age.

In the Blue Hills area the flows consist principally of dark fine-grained basalt. Some of the flows originally contained many small "vesicles" or "bubble holes" produced by expanding gases near the tops of the flows. Those vesicles have since been filled with secondary minerals, producing what is called amygdaloidal texture in the basalt.

In the quarry in sec. 28, T. 24 N., R. 1 E. on Sinclair Inlet, where several flows are discernible, the maximum thickness of individual flows is about 30 feet (fig. 6).

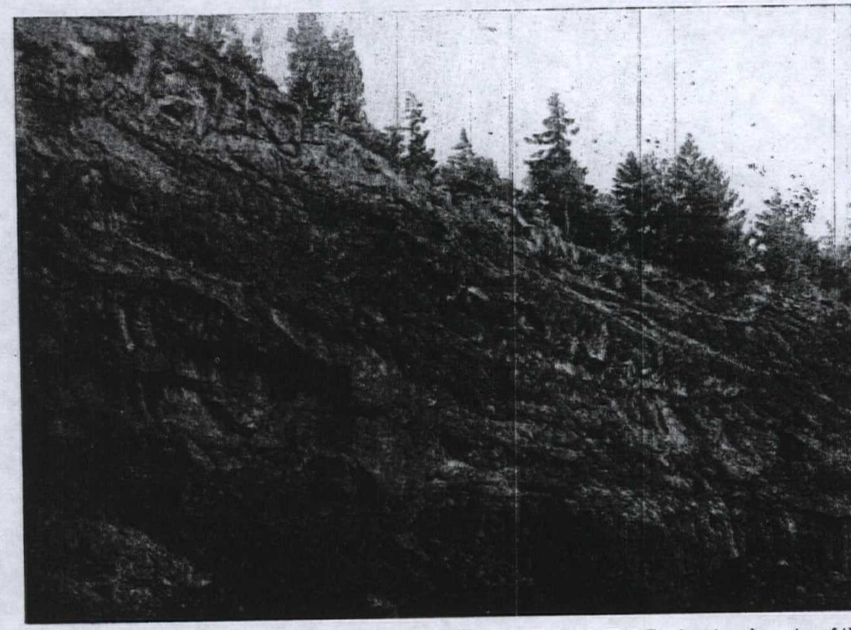


FIGURE 6.—View of basalt quarry along Sinclair Inlet, in sec. 28, T. 24 N., R. 1 E., showing character of the volcanic rocks. Several flows are discernible.

The total thickness of this volcanic formation is not known. In an oil-test well (22/1W–11J2), the drill entered these volcanic rocks at a depth of about 700 feet and had not passed through them at a depth of 6,688 feet.

SEDIMENTARY ROCKS

A thick sequence of marine sedimentary rocks crops out in the sea cliffs near the southern end of Bainbridge Island, and in the opposite shore of the Kitsap Peninsula from Waterman to Orchard Point.

Similar rocks are exposed also in the entrance to Dyes Inlet at the western end of the Port Washington Narrows (pl. 1). They consist of conglomerate, sandstone, and shale composed mainly of erosional products from a volcanic terrain. They were described and named the Blakeley formation by Weaver (1912, p. 10–22), who later assigned them an Oligocene age (1916, p. 166). The total measured and described thickness of this formation in Kitsap County is more than 8,500 feet (Weaver, 1937, p. 151), and its base and upper surface are not exposed.

The formation was folded and was later beveled by erosion in late Tertiary time. The strata, once practically horizontal, are now inclined at angles of 45° to nearly 90° (fig. 7). A marked angular unconformity exists between this formation and the overlying Pleistocene sedimentary materials.

FIGURE 7.—Steeply dipping strata of the Blakeley formation of Weaver, exposed along the beach in sec. 8, T. 24 N., R. 2 E.

QUATERNARY ROCKS

ADMIRALTY DRIFT

The oldest known geologic unit of the Pleistocene series in the Puget Sound basin was named the Admiralty drift by Willis (1898). Where it is exposed it consists chiefly of blue-gray clay but contains strata of sand, gravel, and lignite, and a few thin beds of white volcanic ash. A few discontinuous pods or lenses of glacial till also have been found in the Admiralty (Willis, 1898, p. 153; Bretz, 1913, pp. 175–177). In Snohomish County, Wash., this formation has been called the Admiralty clay (Newcomb, 1953, p. 13).

The upper surface of the Admiralty drift is marked by an erosional unconformity which is below sea level in most places in Kitsap County but is exposed in a few places in the lower parts of sea cliffs.

The Admiralty drift crops out along the beach just south of Fragaria in southeast Kitsap County. There it consists of interbedded clay and sand. The clay is blue-gray and massive but contains some calcareous concretions. The sands are medium grained but in places are sufficiently clayey and impermeable to perch water in the overlying more permeable sands and gravels.

In the sea cliff at Point Southworth (sec. 1, T. 23 N., R. 2 E.) an exposure of the Admiralty drift is chiefly blue-gray silty clay. There individual strata have been greatly deformed, apparently by the subsequent overriding of the area by the Vashon glacier.

Because there are only a few outcrops where the Admiralty drift can be examined, its character is known mainly from well logs. In most well logs it is described as being composed of fine-grained materials, mainly clay and fine sand. Whether all the deeper unconsolidated materials described in well logs belong to the Admiralty drift, or to an older undifferentiated depositional unit is not known. In many drillers' logs it is impossible to separate soft sedimentary rocks of Tertiary age from the overlying Pleistocene materials because of the similarity of the rock descriptions. Many of the deeper wells in the county have been drilled through the Pleistocene materials and continued into the Tertiary sedimentary rocks without any observation by the drillers of a change in formation. Drilling speed, which might give an indication of that break in lithology, was generally not recorded, so that in many wells where the Pleistocene materials have been completely penetrated their thickness is not determinable from well logs.

ORTING GRAVEL

The Orting gravel, which consists chiefly of stream-deposited sand and gravel, rests unconformably upon the Admiralty drift. It was first described in the Orting area of Pierce County by Willis (1898).

In Kitsap County, the Orting gravel consists of sand and gravel but includes, at the top, fine-grained materials which were described by Willis (1899) as a part of the Orting and which in this report are named the Kitsap clay member.

LOWER MEMBER

The lower member of the Orting gravel is best exposed in road cuts along Olalla Creek in the southeast part of the county, where it consists of interbedded lenticular deposits of sand and gravel. The materials generally are slightly cemented and at places are rusty brown in color.

A 25-foot stratum of uniform medium gravel with a matrix of coarse sand is exposed in the abandoned county gravel pit located half a mile northwest of Olalla. These materials are sufficiently cemented as to stand with a vertical face. The gravel is composed predominantly of volcanic rocks, though granitic and metamorphic rock types are common. This stratum, which is at the top of the lower member, is underlain by cross-bedded sand and gravel and overlain by clay and lignite.

A stratigraphic section of the lower member, measured along the west side of Colvos Passage about 1¼ miles south of the Kitsap County line (p. 18), is 108 feet thick and consists of bedded sand and gravel, and an 18-foot stratum of laminated clay. As at Olalla, the individual strata are lenticular and pinch out in short distances.

Other good exposures of the lower member of the Orting gravel are in the sea cliff near La View on the northern end of Bainbridge Island, and in the sea cliff immediately north of Fletcher Bay along the west shore of that island. Several thin strata of clay and silt are interbedded with the sand and gravel in both of these exposures.

The lower member also crops out in the sea cliff half a mile east of Gilbertson (sec. 19, T. 25 N., R. 2 E.). Here coarse gravel strata containing cobbles up to 6 inches in diameter are interbedded with finer grained materials.

Because the lower member of the Orting gravel rests unconformably upon the Admiralty drift, its thickness is in large part controlled by the irregularities in the Admiralty surface. Thicknesses of 300 feet or more of sand and gravel of the lower member were deposited in valleys, while little or no material was deposited upon the hills of the Admiralty surface. The top of the lower member ranges from 100 feet above to 200 feet or more below sea level, being dependent upon the structure given to this unit by a subsequent deformation.

Well 24/1–25E2, located near Port Orchard, penetrated sand and gravel strata from about 225 to 540 feet below sea level. These strata are believed to belong to the lower member of the Orting. They probably were deposited near the center of a valley in the post-Admiralty erosion surface. As the configuration of the post-Admiralty erosion surface is not known, the extent and direction of the thicker and more productive water-bearing zones of the lower member are also unknown.

Well 27/2–17A1, located near Port Gamble in the northern part of the county, was drilled to a depth of 142 feet. This well penetrates 131 feet of clay that is believed to be the Kitsap clay member of the

Orting gravel, and 11 feet of sand and gravel that may be the lower member. The sand and gravel contains many marine shells, which may indicate that a marine embayment extended as far south as Kitsap County at the time the lower member of the Orting was being deposited. However, as the lower member of the Orting gravel does not crop out north of Bainbridge Island, its character in the northern part of the county can be inferred only from well logs.

KITSAP CLAY MEMBER

A geologic unit that consists chiefly of clay but contains strata of peat, sand, gravel, and glacial till overlies the lower member of the Orting gravel in Kitsap County and parts of Pierce County. On the basis of lithology, this unit is separated from the lower member of the Orting. It is proposed that the name Kitsap clay member be applied to this unit.

The type section of the Kitsap clay member, which shows its relation to the underlying lower member of the Orting and to the overlying Puyallup sand, is exposed in the sea cliff along Colvos Passage near Maplewood, in Pierce County south of the Kitsap County line (sec. 21, T. 22 N., R. 2 E.). The following sections were measured in barometric traverses up the sea cliff in this area.

Type sections, Kitsap clay member

Materia	Thickness (feet)	Altitude at top of stratum (feet)
Section 1, at Maplewood		
Till of Vashon age: Till, gray	6	261
Puyallup sand: Sand, brown	130	255
Orting gravel: Kitsap clay member:		
Clay, laminated	33	125
Peat	2	92
Clay, gray-brown, massive	15	90
Covered	75	75
Beach strand		
Section 2, 500 feet north of section 1		
Puyallup sand: Sand and gravel		
Orting gravel: Kitsap clay member:		
Clay, gray, laminated	40	95
Clay, gray-brown, massive	7	55
Peat	3	48
Clay, gray-brown	20	45
Peat	2	25
Covered	23	23
Beach strand		

Type sections, Kitsap clay member—Continued

Material	Thickness (feet)	Altitude at top of stratum (feet)
Section 3, 2,400 feet south of section 1		
Puyallup sand: Sand, brown		
Orting gravel: Kitsap clay member:		
Clay, laminated, contains several thin strata of peat	15	184
Till	7	169
Clay, sand, and some stratified gravel	15	162
Till	5	147
Clay, laminated; contains some sand strata	12	142
Till and laminated clay	8	130
Clay, laminated; contains some sand strata	12	122
Lower member:		
Sand and gravel, stratified	30	110
Clay, laminated	18	80
Gravel, medium, iron-stained	12	62
Sand, layered	12	50
Gravel, medium, iron-stained	18	38
Sand and gravel, cross-bedded	18	20
Admiralty drift:		
Clay, gray to blue; contains thin strata of peat and white volcanic ash	2	2
Beach strand		

The beds of till in the Kitsap clay member in section 3 are only pods or lenses and are not part of a continuous till sheet. Two of the till strata pinch out within a few hundred feet north of this section. Where the Kitsap clay member is exposed on the sea cliff one-tenth of a mile south of the mouth of Fragaria Creek, in the southwest part of Kitsap County, it contains a lens of till interbedded with clay, silt, and peat.

Fragaria Creek has eroded a narrow canyon into the Kitsap clay member. Several thick, resistant strata of peat or lignite have given rise to small waterfalls along the stream. According to Bretz (1913, p. 180) several prospect tunnels were driven into these lignite strata in hope that back from the outcrop the equivalent unweathered material would be coal.

The Kitsap clay member is well exposed at many localities throughout Kitsap County, as along State Highway 14, between Port Orchard and Gorst; in the old clay pit at Harper (sec. 2, T. 23 N., R. 2 E.); in the sea cliff 1 mile south of Point Southworth (sec. 11, T. 23 N., R. 2 E.); and in the road cut along the highway to Holly (fig. 8).

The Kitsap clay member is well stratified. The clay strata are in most places finely laminated, and the sand and silt also are in thin layers. The thin and prominent stratification contrasts strongly with the thicker bedding of the Admiralty drift.

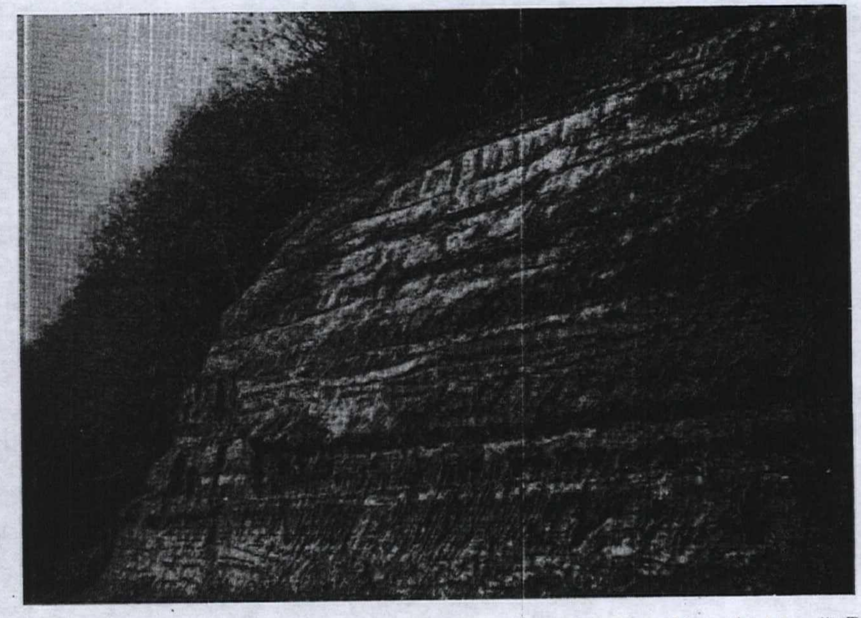


FIGURE 8.—Layered silt and clay in the Kitsap clay member of the Orting gravel in road cut, sec. 17, T. 24 N., R. 2 W.

The thickness of the Kitsap clay member changes from place to place, ranging from less than 30 feet to more than 200 feet. The top of the Kitsap clay member ranges from 50 feet or more below sea level to 200 feet above sea level, according to the structure imparted by subsequent deformation.

In areas where a high proportion of gravel is interbedded with the Kitsap, it could not be distinguished in detail from the lower member of the Orting gravel and, in part, was included with that gravel unit on the geologic map (pl. 1).

PUYALLUP SAND

The Puyallup sand comprises the major part of the pre-Vashon materials that are exposed in Kitsap County. This formation was first described in the Tacoma area by Willis (1898).

In Kitsap County the Puyallup sand consists of fine-grained, well-sorted sands deposited by streams or in lakes. Deposits range from finely laminated sand and silt to thick, massive strata of sand. Current and deltaic bedding are present in most places. Gravel lenses of small to medium-sized pebbles are common in the basal part of this formation.

The Puyallup sand rests conformably upon the Kitsap clay member of the Orting gravel but is overlain unconformably by glacial materials.

The thickness of the Puyallup sand differs greatly throughout the county, the maximum being about 300 feet.

Good exposures of the Puyallup sand can be seen at many places in the county, as along the highway just south of Illahee in sec. 7, T. 24 N., R. 2 E.; along the sea cliff at Venice in sec. 2, T. 25 N., R. 2 E.; and along the sea cliff 1 mile east of Indianola in sec. 14, T. 26 N., R. 2 E. The bluff just northwest of Kingston in sec. 25, T. 27 N., R. 2 E., shows the thick, massive character of some of the sand strata in this formation.

VASHON DRIFT

The name Vashon drift was given by Willis (1898) to the extensive till sheet and associated deposits that were deposited in the Puget Sound basin during the advance and retreat of an ice tongue from the north during the latest glacial epoch.

TILL

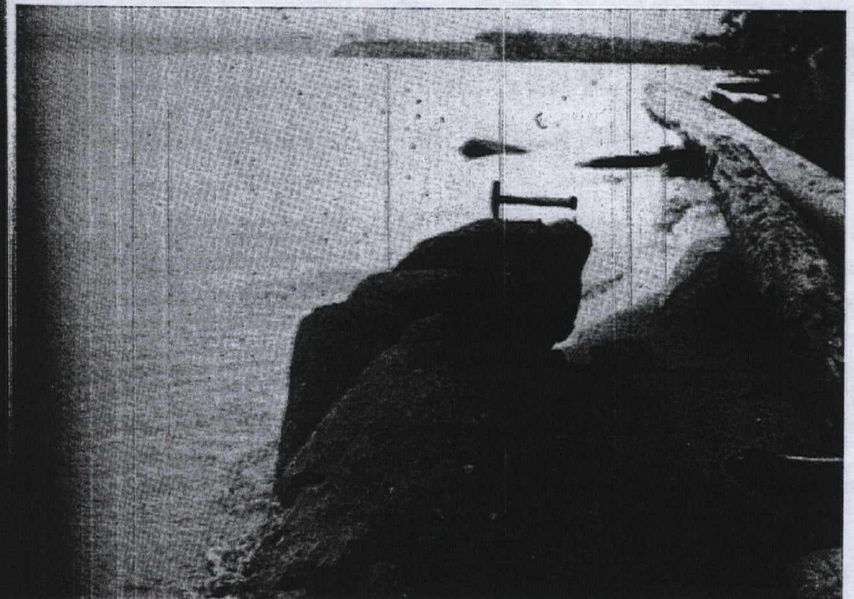
The glacial till of Vashon age is an unsorted mixture of clay, silt, sand, gravel, and boulders that was deposited principally as a basal till beneath the ice. Such a range in grain size, accompanied by the tremendous pressure produced by the weight of the ice during deposition, results in a hard, compact, impermeable rock having the appearance and some of the characteristics of concrete. The till in the Vashon drift is generally light gray. It is locally termed "hardpan" and is commonly so hard that blasting is required in the construction of dug wells. In many places the character of the till is a clue to the character of the underlying material; an excessively sandy till usually overlies sandy material, whereas an excessively clayey till usually overlies clayey material.

The basal till is commonly overlain by a few feet of superglacial till—the part of a glacier's rock load that is deposited as the glacier melts. It differs from the basal till in being less compact and better sorted, as many of the smaller particles have been washed away by melt water. In Kitsap County the superglacial till contains most of the large erratic boulders that are associated with the Vashon drift.

The front of a glacier advances when the rate of forward movement exceeds the rate of melting, and retreats when melting exceeds the forward movement. Changes in one, or both, of these factors can cause a change in rate or direction of movement of the ice front. The recession and readvance of an ice front may result in the deposition of two till sheets in the area of readvance. Such a twofold till of the Vashon drift occurs in the Port Orchard area. The inte[r]till materials consist of sand and gravel ranging in thickness from a few feet to 30 feet. Other exposures of this twofold till occur at the southern end of Bainbridge Island, at the southern end of the

Manette Peninsula, and in the Bremerton area. In Kitsap County the north-south extent of the readvance is believed limited to a few miles.

Because on the uplands the Vashon glacier advanced chiefly over the Puyallup sand, the till and melt-water deposits there are distinctly sandy. The included boulders are of a great variety of rock types, though volcanic and granitic types predominate. Locally, as in areas south of the Blue Hills, the till contains many large fragments of basalt which were undoubtedly derived from the rock of those hills. Close to areas of outcrop of the Blakeley formation of Weaver, the larger fragments in the till are mainly of those sedimentary rocks.



9.—Wave-rounded blocks showing the typical hard, compact character of the till of the Vashon drift.

[illegible] weight and pressure of the ice on the underlying sedimentary [illegible]rials resulted in their deformation in some places. Figures 11 [illegible] 12 show layered sand and clay of the Puyallup sand that were [illegible]pled by ice pressure. At places, strata of the older Admiralty [illegible] also have been deformed.

[illegible]bles and boulders that differ in composition from the local rock [illegible]re termed "glacial erratics." They range greatly in size and [illegible]sition in Kitsap County and in many places form the boulder [illegible]nts that are common on the beaches of Puget Sound.

FIGURE 10.—Puyallup sand and advance outwash overlying Admiralty drift at Point Southworth.

FIGURE 11.—Layered sand and silt in the Puyallup sand that have been greatly contorted by ice shove, exposed in sea cliff, sec. 18, T. 28 N., R. 2 W.

An extremely large erratic boulder of volcanic rock lies beside the highway leading north to Illahee in sec. 6, T. 24 N., R. 2 E. Rounded erratic rocks of cobble size near the summit of Green Mountain indicate that the surface of the glacier was at an altitude

FIGURE 12.—Clay that has been injected upward into the Puyallup sand by ice shove, exposed in sea cliff, sec. 18, T. 28 N., R. 2 E.

above 1,690 feet. As the base of the glacier is known to have been at depths of several hundred feet below sea level, the total thickness of the Vashon glacier in that vicinity at one time must have exceeded 2,000 feet.

Marine fossils were found in the till in the low sea cliff along Skunk Bay in the SE¼NE¼ sec. 18, T. 28 N., R. 2 E., in the northern part of the county. This is the only outcrop known in Kitsap County where fossil shells can be observed in Pleistocene deposits. At this locality the till overlies a fossiliferous sandy clay that is believed to be of pre-Vashon age. The fossils in the till probably were derived from the underlying stratum.

OUTWASH

Glacial outwash is material that was deposited beyond the ice front by glacial melt-water streams. Streams that issue from a glacier usually are heavily loaded with rock particles. Near the ice front, poorly sorted, rudely stratified sand and gravel are deposited. At greater distances from the ice, finer grained and more evenly stratified materials are generally deposited. Figures 13 and 14 show the typical character of the glacial outwash material found in Kitsap County.

Part of the glacial outwash deposits are older than the till of the Vashon glaciation and part are younger. Glacial outwash materials that are deposited as a glacier advances into an area are termed "advance outwash," and materials deposited during the recession are

FIGURE 13.—Advance outwash gravels exposed in a 20-foot road cut along the slope of Hood Canal in sec. 9, T. 24 N., R. 2 W. These strata probably owe their tilt to deformation by ice.

FIGURE 14.—Recessional outwash gravel of the Vashon drift, in face of borrow pit, sec. 16, T. 24 N., R. 2 W., showing their poorly sorted character.

termed "recessional outwash." In Kitsap County these units are separated by the stratum of glacial till deposited when the area was covered with ice, except in small areas where the till was removed by erosion during the retreat of the ice.

Outwash from the Vashon glacier varies greatly in character, thickness, and extent throughout the county. The outwash gravel is composed of many types of rocks, volcanic and granitic types predominating. Individual particles range in shape from well rounded to subangular.

The advance outwash of the Vashon glacier is a difficult unit to show on a geologic map owing to its varying thickness and erratic occurrence, and was mapped with the Puyallup sand in order to differentiate it from the impermeable till.

Ice-marginal streams, flowing along the advancing ice lobes that pushed south into the valley areas, deposited outwash materials which now plaster some of the slopes leading to Puget Sound and the larger valleys. Such deposits of sand and gravel may obscure the character of the materials that form the cores of the plateau areas, and may lead to misconception as to the nature of the materials underlying these plateaus. In sec. 9, T. 24 N., R. 2 W., such a deposit of advance outwash was overridden and deformed by the advancing ice (fig. 13).

The recessional outwash of the Vashon glaciation is widely distributed in the county and consists mainly of a thin mantle of sand and gravel resting on the till. This thin mantle is not a mappable unit in most places and on plate 1 has not been separated from the till. The thicker deposits in melt-water channels and plains were mapped separately and are shown on plate 1.

A deposit of recessional outwash sand accumulated during the waning stages of the Vashon glaciation in the Gorst Creek–Union River trough. This sand is fine grained, and in many places it shows fine bedding planes where differential weathering on outcrops has brought them into relief. This unit is shown on plate 1 as the Gorst Creek outwash.

The sand of the Gorst Creek outwash accumulated in quiet water and buried many large ice blocks. Melting of these ice blocks resulted in the formation of kame and kettle topography and in the deformation of the strata. Similar sands were noted in the Blackjack and Burley Creek valleys, but there they were not differentiated from the underlying Puyallup sand.

Figure 15 is a summary of the depositional units of Pleistocene age in Kitsap County.

Designation in section	Depositional unit name		Character and extent	Thickness, in feet	Water-bearing properties
A	Vashon drift	Recessional outwash	Discontinuous bodies of unconsolidated silt, sand, and gravel. Deposited by meltwater of the Vashon glacier. Includes Gorst Creek outwash	0-100	May yield small to moderate supplies of ground water sufficient for domestic supply where the deposits have considerable thickness
B		Till	Extensive till sheet which mantles most of the upland areas of the county. Till varies greatly in composition and compactness	0-80	Essentially impervious, but may yield small supplies of perched ground water
C		Advance outwash	Discontinuous bodies of unconsolidated silt, sand, and gravel. Deposited by melt-water streams from the advancing Vashon glacier	0-50	Yields moderately large to large quantities of water where deposits extend below the water table
D	Puyallup sand		Principally stratified sand. Contains irregular lenses of fine gravel, and thin strata of clay and silt. Underlies the Vashon drift throughout most of the county	0-300	Much of formation lies above water table. Gravel lenses yield moderately large quantities of water. Sand yields small quantities
E	Kitsap clay member of Orting gravel		Principally laminated blue clay. May contain irregular lenses of medium gravel. In places contains peat and till strata	0-200+	Gravel lenses yield small to moderate quantities of water. Clay and till yield little or no ground water
F	Lower member of Orting gravel		Principally stratified sand and gravel. May be stained buff or orange colored in outcrop. Contains some clay strata	0-300+	Yields large quantities of water
G	Admiralty drift		Principally massive blue clay and silt; deformed in most places. Contains till, volcanic ash, peat or lignite, sand, and some gravel strata. Top of formation usually near or below sea level	0-400 or more	Clay, silt, and till strata yield little or no ground water. Gravel may yield small to moderate quantities of water. Successful wells in Admiralty drift are few in number

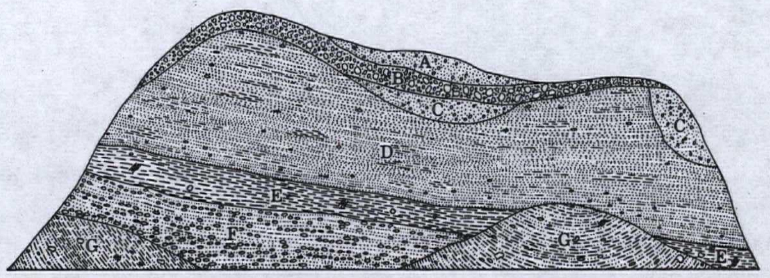


FIGURE 15.—Summary and diagrammatic cross section of Pleistocene depositional units, Kitsap County, Wash.

RECENT MATERIALS

Postglacial deposits of small extent exist in many areas throughout the county. Alluvium and peat have filled some of the postglacial ponds. Streams have formed numerous small deltas extending into Puget Sound, and a soil cover ranging from several inches to several feet in thickness now mantles most of the county.

GEOLOGIC HISTORY

A knowledge of the sequence of geologic events in an area, as interpreted from rock outcrops and well records, helps in understanding

the extent and occurrence of the geologic units. These in turn aid in an understanding of the occurrence of ground water in the area.

TERTIARY PERIOD

During early Tertiary time a series of volcanic rocks spewed forth from fissures or cones and accumulated to thicknesses of many thousands of feet over a large part of the area that is now western Washington. Part of the rocks were erupted beneath the sea. In Kitsap County and the adjacent area a long period of quiescence followed the volcanic activity. During that time thousands of feet of marine sedimentary rocks accumulated above the volcanic rocks.

During late Miocene time these formations were deformed into large northwest-trending folds, which produced the ancestral Cascade Mountains. Erosion reduced these considerably in the following Pliocene epoch. Deformation occurred again near the close of the Tertiary period, producing a large north-trending arch that forms the present Cascade Mountains. The Puget Trough and the Olympic Mountains are believed to have been brought into existence during this deformation.

QUATERNARY PERIOD

The filling of the Puget Sound basin with sedimentary materials is believed to have started in late Tertiary or early Pleistocene time. The oldest known Pleistocene sedimentary materials are called the Admiralty drift. They are principally fine-grained materials that are believed to have accumulated in a fresh-water lake or lakes. Such a lake could have been formed by the impounding of a northward-flowing drainage system by a tongue of ice that originated in the present British Columbia and flowed south and west from the Puget Sound basin by way of the Straits of Juan de Fuca. The thin strata of volcanic ash found in this unit indicate that some volcanic activity was occurring in nearby areas during this time. The occurrence of glacial till in the Admiralty drift proves that an ice tongue or tongues occupied part of the Puget Sound basin during Admiralty time. Whether this till was deposited by coalescing glaciers that moved out from the Cascade and Olympic Mountains, by a lobe from a northern ice sheet, or by both is not known. Locally, woody material accumulated in shallow ponds or swamps and gave rise to the existing lenses of peat and lignite. Streams, and possibly lake currents, deposited trains of sand and gravel which occur as lenses of coarse material interbedded with those of finer texture.

In time the lake or lakes were drained, possibly as a result of recession of the ice lobe, and the area was subjected to a period of erosion which produced a surface of low to moderate relief. Some folding of

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the early Pleistocene sedimentary materials occurred at the time of their deposition or during the succeeding period of erosion.

The period of erosion was followed by one of deposition, caused by a rise in base level. Stream-deposited sand and gravel accumulated in the lowland areas on the eroded surface of the Admiralty drift to a thickness locally greater than 150 feet. They are known as the lower member of the Orting gravel. Their deposition was succeeded in Kitsap County and parts of Pierce County by the deposition of fine-grained sedimentary materials, which form a unit that has been called the Kitsap clay member of the Orting gravel in this report. The till that occurs in this unit indicates that glacial ice was again present in the Puget Sound area during part of the period of its deposition.

Deposition of the Kitsap clay member was succeeded by the accumulation of fine-grained stream and lake-deposited sedimentary materials named the Puyallup sand. The formation consists principally of sand but also contains some gravel and clay lenses. It accumulated to a thickness of several hundred feet and produced a broad, flat surface over most of the Puget Sound basin. The deposition was brought to a close by uplift of the area. This change in base level resulted in dissection of the uplifted plain by streams which carbed steep-sided valleys, as much as 600 or 700 feet deep. These valleys largely determine the present configuration of the waterways of Puget Sound. Broad warping of the previously deposited sedimentary materials occurred in the final stages of their deposition, or during the following period of erosion.

The period of canyon cutting was brought to a close by the advance of the Vashon ice sheet into the region. This ice sheet was part of a large glacier that formed in British Columbia and Vancouver Island. One lobe of the glacier pushed southward into the Puget Sound basin, whence advance ice tongues moved farther southward into the existing valleys and canyons. Drainage was diverted to the marginal areas of the ice tongues, resulting in the deposition of outwash materials on the valley slopes. As the ice moved farther south, the depth of ice increased in the occupied valleys, and marginal melt-water streams spilled over the lower divides and produced diversion channels across portions of the partially dissected uplands. Fine-grained materials were deposited in marginal lakes and ponds, and rudely sorted sands and gravels were deposited in channels and broad outwash plains on the uplands. The ice tongues later filled the valley areas and spread over the uplands, depositing a mantle of glacial till. Thus the ice tongues coalesced and eventually covered most of the Puget Sound basin. In Kitsap County the Vashon glacier is believed to have exceeded 2,000 feet in thickness. Melt water from this ice lobe

drained southward, through the large channels north and west of the town of Gate in Thurston County, and out to the Pacific through what is now the lower Chehalis River valley.

Near the close of the Pleistocene epoch, the front of the Vashon ice lobe began melting back from the Puget Sound basin. The uplands and hills were the first areas free of ice. Melt-water streams flowed across some of the exposed areas, eroding some of the earlier deposits and depositing sand and gravel outwash materials in broad outwash channels. Deltas formed at many places where these streams terminated in lakes and ponds that were impounded by the ice tongues, which still occupied the valley areas. Foreset bedding of one such delta can be seen in the gravel pit along the Bremerton-Seabeck highway in sec. 7, T. 24 N., R. 1 E. With continued waning of the ice, melt-water streams shifted to channels located at progressively lower altitudes. With the complete removal of the ice from the Puget Sound basin, the drainage again resumed its general northward course.

Ice erosion during the advance of the Vashon glacier into the area, and during the subsequent retreat of the ice front, so greatly deepened and modified the pre-Vashon drainage system that its exact configuration can now be only inferred.

During postglacial time, large deltas have formed at the mouths of the larger streams that discharge into Puget Sound. Peat and silt deposits have accumulated in ponds that developed on the irregular glacial topography, and a relatively thin soil has developed throughout most of the area. Postglacial streams have eroded deep canyons in the uplands, and slumping and wave erosion have steepened many of the slopes extending from the uplands to the waterways of Puget Sound.

Following is a chronologic summary of the late geologic events that have occurred in Kitsap County and vicinity:

Tertiary:

A. Period of volcanism in which many thousands of feet of volcanic rocks were deposited over a large part of the area that is now western Washington.

B. Period of marine deposition in which many thousands of feet of sedimentary materials were deposited on the volcanic rocks.

C. Period of deformation that uplifted the Cascade and Olympic Mountains and produced the Puget Sound basin. Deposition in the Puget Sound basin probably began at this time.

Quaternary:

D. Partial filling of the basin with the Admiralty drift and possibly other unknown deposits. Glaciation of part or all of the basin occurred during this period of deposition. Some warping of the sedimentary rocks occurred during or shortly after their deposition.

E. Period of erosion producing a terrain of low or moderate relief on the earlier Pleistocene sedimentary rocks.

F. Period of deposition.
  a. Deposition of stream-laid gravel, sand, and some clay strata called the lower member of the Orting gravel.
  b. Deposition of lake and pond deposits, principally clay and peat called the Kitsap clay member of the Orting gravel. Isolated bodies of glacial till suggest glaciation of part of the basin.
  c. Deposition of stream and lake deposits, principally sand, called the Puyallup sand.

G. Relative lowering of base level producing a period of canyon cutting The valleys that now form the waterways of Puget Sound were formed during this period. Some warping of the Pleistocene sedimentary materials probably occurred.

H. Advance of the Vashon ice sheet into the basin.
  a. Deposition of associated glacial advance deposits, outwash, and lake sedimentary materials.
  b. Deposition of a till sheet.

I. Recession of the Vashon ice sheet.
  a. Deposition of associated glacial advance deposits; outwash and lake sedimentary materials.
  b. Deposition of a till sheet.

J. Period of erosion and deposition; resulting in the Recent partial filling of the Pleistocene valleys and seaways and cutting of the post-Pleistocene valleys and canyons.

GROUND WATER

GENERAL FEATURES OF GROUND-WATER OCCURRENCE

DEFINITION OF GROUND WATER

The interstices or voids in rock materials below a certain depth are usually saturated with water under hydrostatic pressure. Water within this zone of saturation is termed "ground water," and water above the zone, but below the surface of the ground and not saturating the rock materials, is termed "vadose water."

In many places, an impermeable stratum may impede the downward movement of vadose water and cause it to accumulate to form a zone of saturation. Water in such a zone is termed "perched ground water."

An aquifer is a water-bearing formation, group of formations, or part of a formation that is capable of yielding water to a well or spring. Many rock materials, even though saturated, are incapable of yielding water because of their low permeability. Therefore, in an attempt to pierce an aquifer, it may be necessary to drill a considerable distance into the zone of saturation.

THE WATER TABLE

In permeable materials the top of the zone of saturation—the surface below which all interconnected voids are saturated—is the

"water table." This is the level at which water will stand in a well sunk into the zone of saturation. The surface of a perched zone of saturation is termed a "perched water table."

The water table is generally a sloping surface, having a gradient in the direction of ground-water movement. Movement is from points or areas of recharge, where water is added to the ground-water body, to points or areas of discharge. The gradient of the water table is dependent upon the thickness and permeability of the rock materials below the water table and the amount of water moving through the materials. In materials of low permeability the gradient needed to move a given amount of water from a point of recharge to a point of discharge is greater than in materials of higher permeability. The presence of many different areas of recharge and discharge, and variable permeabilities of the rock materials, tend to make the water table an irregular surface.

The water table fluctuates, owing to changes in the amounts of recharge and discharge. A rise of the water table, generally accompanied by a steepening of the water-table gradient, occurs during periods of recharge; a lowering of the water table, accompanied by a reduction of the water-table gradient, occurs in periods of little or no recharge.

UNCONFINED AND CONFINED GROUND WATER

In an area where only permeable materials exist, there will be but one water table. All wells drilled in the area will encounter water when the water table is reached, and water levels in the wells will define that surface. Water occurring under water-table conditions is termed "unconfined" ground water.

Where ground water moves beneath some impermeable stratum and is confined there under pressure, it is termed "confined" or "artesian" ground water. If no saturated zone occurs above the impermeable stratum, a water table does not exist there, and well drills will not encounter water until they have passed through the impermeable stratum. The water then encountered rises in the casing to a height corresponding to the pressure head on the confined ground water.

Confined ground water has a pressure surface (piezometric surface) which is analogous to the water table but whose level may be greatly different from that of an overlying or adjacent water table. This is usually true when the recharge to the confined aquifer occurs some distance away and is not related to the local water table. The piezometric surface, like the water table, fluctuates in response to recharge and discharge.

Numerous impermeable and permeable zones may exist one above

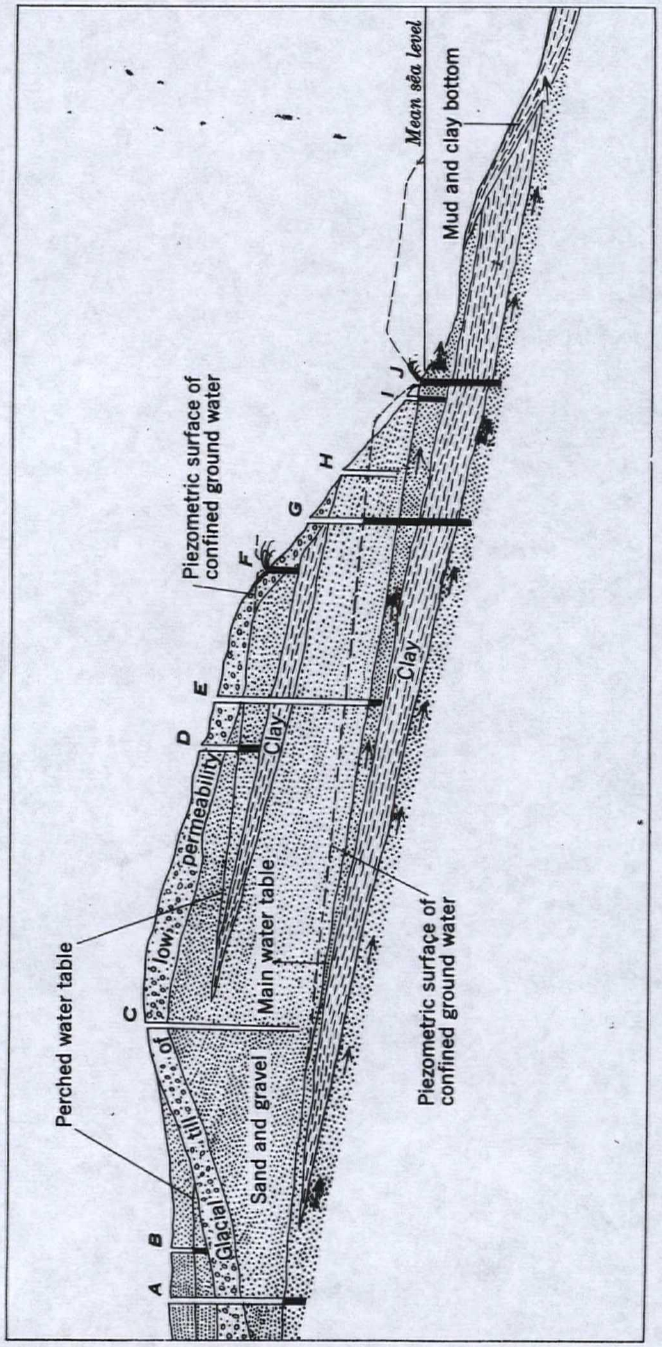

FIGURE 16.—Diagrammatic section showing various occurrences of ground water. Arrows indicate direction of ground-water movement. Well *A* yields unconfined water from below the water table; well *B* yields perched water from a water body perched on glacial till; at well *C* water was not encountered owing to insufficient depth; well *D* yields perched water from water body perched on clay zone; well E yields unconfined water from below the water table; well *F* yields confined perched ground water and flows because land surface is lower than the head developed on the water body as a result of the presence of the till cover; well *G* yields confined water from water body confined by clay zone; at well *H* water was not encountered owing to insufficient depth; well *I* yields unconfined water from below the water table; and well *J* yields confined ground water and flows because the land surface is below the piezometric surface.

the other. The water-pressure surface may be different for each of these permeable zones. Where the pressure is sufficient to raise the water above the adjacent land surface, a well will flow. Such a well is termed a "flowing artesian well."

Several occurrences of ground water are illustrated schematically in figure 16. All these are typical in Kitsap County.

GROUND-WATER RECHARGE

The chief source of ground-water recharge is precipitation. Part of the precipitation falling on an area will generally flow off as surface runoff, part will evaporate, and another part will percolate into the soil.

Precipitation that enters the soil will in part replace previously depleted soil moisture and be evaporated or drawn up by plants and transpired back into the atmosphere. The rest will continue to percolate downward and eventually reach the water table. Variations in soil and rock permeability, depth to the water table, topography and vegetation, and the amount and kind of precipitation all produce variations in the amount of ground-water recharge from time to time and place to place.

Often there is a noticeable lag in time between periods of high precipitation and the rise of the water table that reflects that precipitation. Such a lag is dependent upon the depth to the water table and the permeability of the intervening rock materials.

Some of the lakes and ponds in Kitsap County that are perched above the water table by the mantle of glacial till supply some recharge to the underlying water table. This recharge is effected by slow percolation through the lake bottom deposits and the underlying till.

Irrigation can be considered a form of artificial recharge, as a part of the water spread over the ground will generally reach the underlying aquifers.

GROUND-WATER DISCHARGE

Ground-water discharge is the exit of water from a ground-water body. It is accomplished by flow onto the surface or directly into the sea and by evaporation, transpiration, and pumping from wells.

Discharge to the surface usually occurs through springs or seeps where the land surface intersects a water-bearing zone. In many places such discharge will occur beneath the surface of streams, lakes, or marine water bodies where its presence is not discernible.

Evaporation occurs where the water table lies close enough to the surface of the ground so that water can be removed into the atmosphere.

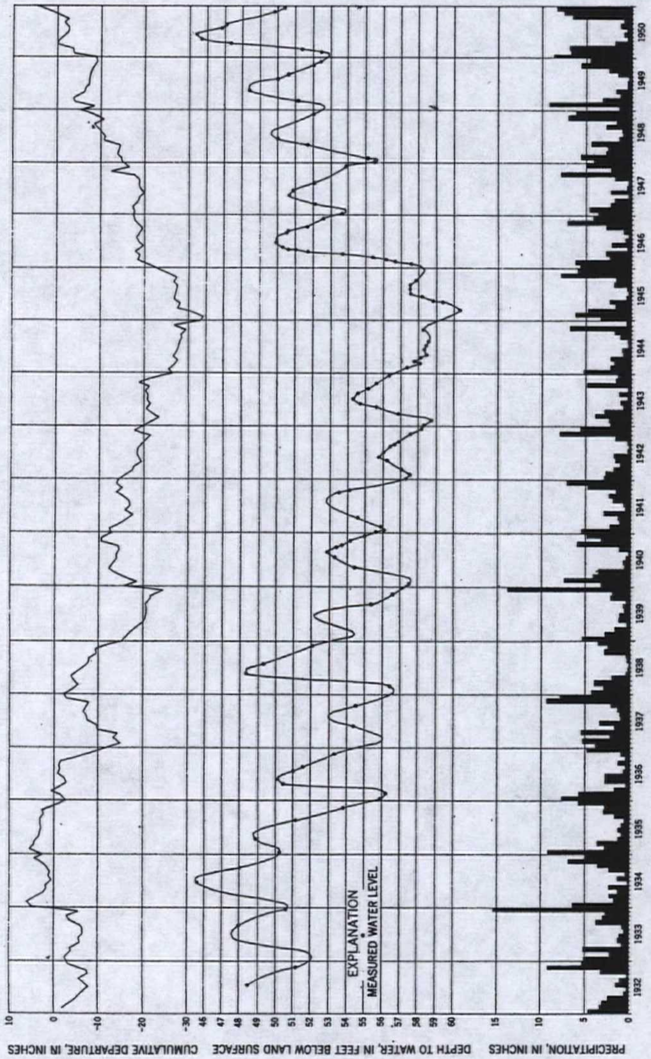

FIGURE 23. Monthly cumulative departure from progressive average (5-year) precipitation at Bremerton, Wash., a hydrograph of well 23/1-2C2 located near Port Orchard, and monthly precipitation at Bremerton, 1932-50.

Figure 3 shows that the average annual precipitation in Kitsap County ranges from less than 20 inches in the northern part to more than 70 in the western part. Only a part of that precipitation reaches the water table, and only a part of that is available for ground-water withdrawal. On the basis of meager data the writer estimates that in areas having about 20 inches of precipitation, the perennial yield will be perhaps as much as ½ acre-foot per acre per year; in areas having 25 to 30 inches of precipitation, as much as 1 acre-foot per acre; in areas having 30 to 50 inches of precipitation, as much as 1 to 2 acre-feet per acre; and in areas having 50 to 70 inches of precipitation, as much as 2 to 3 acre-feet per acre. However, the local geological situation, especially the presence of relatively thick impervious capping layers, like the till, will reduce those estimates in many places.

At present, only a small portion of the available ground water is being withdrawn. The amount is likely to increase, however, and in a number of areas in the county the pumping might easily increase to or beyond the perennial yield. In order to provide a basis for proper administration by the State of the laws affecting the ground-water resources of the county, a minimum network of observation wells and precipitation and stream-gaging stations should be maintained. Data from these, together with data on ground-water withdrawals, will provide basis for more refined estimates of the perennial yield of specific areas.

GROUND-WATER UTILIZATION

DOMESTIC SUPPLIES

By far the greatest number of wells in Kitsap County develop water for domestic use. The domestic use of water includes both household and farmstead use, and can be supplied by small-capacity wells. The average daily consumption for this type of development is probably less than 500 gallons per well.

MUNICIPAL SUPPLIES

All the towns and most of the larger communities are supplied by public distribution systems (fig. 24). The city of Bremerton has the largest system in the county. It utilizes both surface and ground water. Surface water from Heins Creek, and other small streams flowing off the Blue Hills, is collected by Gorst Creek and diverted into the system. Part of the flow of the Union River is diverted in sec. 34, T. 24 N., R. 1 W. and utilized. Besides these surface streams, six wells located in sec. 33, T. 24 N., R. 1 E. and part of the flow of Anderson Creek, a very small spring-fed stream in this section, are utilized. As all the wells are flowing, their natural flow is used throughout the year, and the wells are pumped only when other supplies are

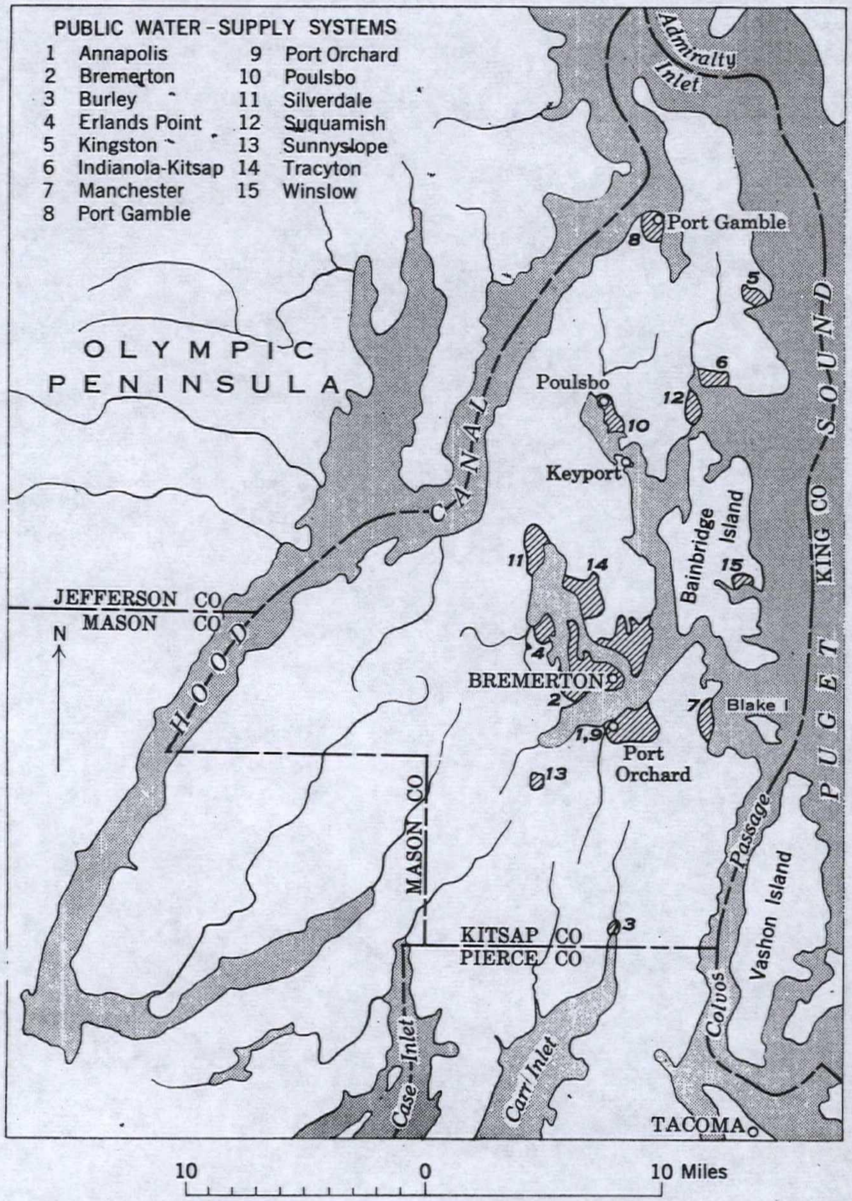

FIGURE 24.—Map of Kitsap County, Wash., showing areas supplied by the larger public water-supply systems.

short. Figure 25 shows the amount of ground water utilized by the Bremerton system during the years 1947–49. The diversion from Anderson Creek is included in the amounts shown on this figure, as the diversion from Anderson Creek represents essentially spring discharge.

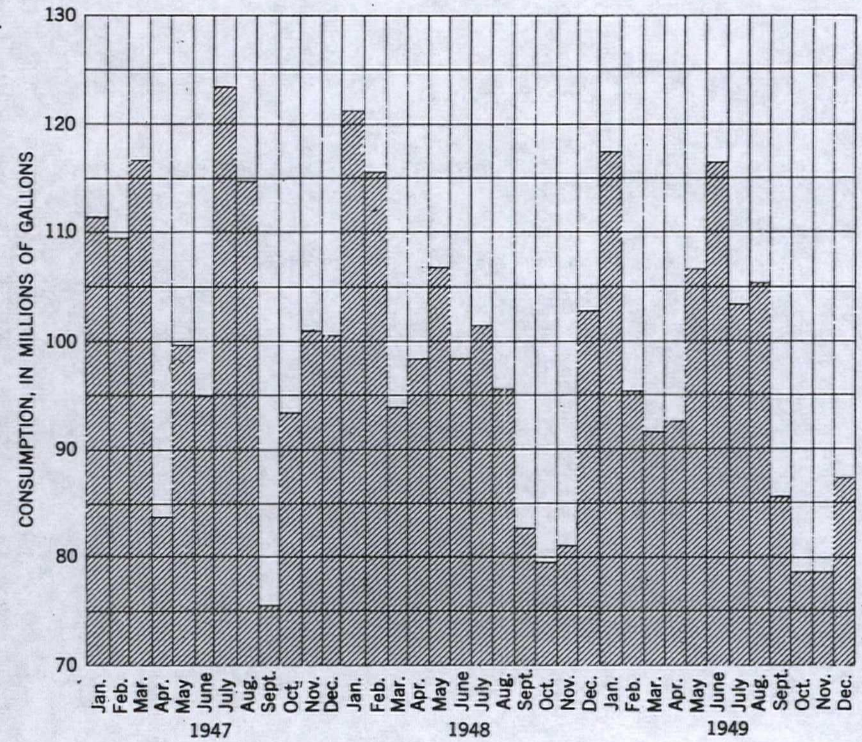

FIGURE 25.—Ground-water consumption by the city of Bremerton, Wash., 1947–49.

Information concerning many of the smaller water-distribution systems is tabulated below; the locations are shown on figure 24.

TABLE 3.—*Public water-supply systems*

[Data from State Department of Health, and water-district authorities]

Water-supply system	Source of water	Storage capacity (gallons)	Population served	Approximate average consumption (gallons per day)
Annapolis	Well	200, 000	1, 500	120, 000
Burley	Well	8, 500	60	----------
Erlands Point	Spring	125, 000	532	40, 000
Kingston	Wells	70, 000	343	15, 000
Indianola-Kitsap	Well, spring, stream	35, 000	700	----------
Manchester	Well	43, 000	450	30, 000
Port Gamble	Springs	400, 000	500	250, 000
Port Orchard	Wells	250, 000	3, 275	860, 000
Poulsbo	Springs	165, 000	1, 275	70, 000
Silverdale	Spring	80, 000	1, 500	70, 000
Suguamish	Wells	228, 000	825	35, 000
Sunnyslope	Well	25, 000	400	----------
Tracyton	Stream and spring	50, 000	400	25, 000
Winslow	Well	----------	600	----------

TABLE 6.—*Materials penetrated in representative wells in Kitsap County, Wash.*—Continued

Materials	Thickness (feet)	Depth (feet)
Well 24/1-3R1		
H. Burton. Altitude about 220 feet. Drilled by T. G. Philpott.		
Dug, no record	15	15
Puyallup sand and Tertiary sedimentary rock(?):		
Clay and sand	68	83
Clay, hard, with some sand	12	95
Sand, water-bearing	5	100

Casing, 6-inch, set to 100 feet.

Materials	Thickness (feet)	Depth (feet)
Well 24/1-5Q1		
M. Peters. Altitude about 40 feet. Drilled by T. G. Philpott, 1949.		
Soil	6	6
Vashon drift:		
Till:		
"Hardpan"	2	8
Puyallup sand:		
Sand and gravel, water-bearing	42	50
Orting gravel:		
Kitsap clay member:		
Clay, blue	110	160

Casing, 6-inch, set to 160 feet.

Materials	Thickness (feet)	Depth (feet)
Well 24/1-11E1		
L. Schuyler. Altitude about 80 feet. Drilled by N. C. Jannsen, 1931.		
Vashon drift:		
Till(?):		
Clay, yellow, with some gravel	17	17
Advance outwash and Tertiary sedimentary rock:		
Gravel and boulders	10	27
Clay, brown	39	66
Boulders and gravel	2	68
Gravel, then brown clay	12	80
Clay, yellow, and boulders	14	94
Clay, brown, and boulders	16	110
Clay, brown	40	150
(no record)	1	151
Clay, brown, and some boulders	10	161
Clay, light brown, sticky	51	212
Sand and grayish clay	11	223
Clay, blue	10	233
Clay, brown	59	292

Materials	Thickness (feet)	Depth (feet)
Well 24/1-12B1		
H. F. Johnson. Altitude about 310 feet. Drilled by N. C. Jannsen, 1932.		
Vashon drift:		
Sand	20	20
Till:		
Gravel, cemented, with sand and boulders	41	61
Advance outwash and Puyallup sand, undifferentiated:		
Sand and gravel, water at 75 feet	14	75
Gravel, loose	8	83
Sand and gravel	1	84

Casing, 3-inch, set to 84 feet.

TABLE 6.—*Materials penetrated in representative wells in Kitsap County, Wash.*—Continued

Materials	Thickness (feet)	Depth (feet)
Well 24/1-12E2		
City of Bremerton. Altitude about 260 feet. Drilled by International Water Supply Ltd., 1942.		
Vashon drift:		
Till(?):		
Sand, clay and gravel	13	13
Pleistocene deposits, undifferentiated:		
Clay, blue	92	105
Clay, blue, with boulders	27	132
Clay, blue, with sand and boulders	60	192
Sand, coarse, and gravel, water-bearing	10	202
Sand, fine	18	220
Tertiary sedimentary rocks, undifferentiated:		
Sand and shale	30	250
Shale, blue, hard, sandy	374	624
Shale, gray	89	713
Shale, gray, and boulder	32	742
Not recorded	172	914

Casing, 8-inch, set to 914 feet.

Materials	Thickness (feet)	Depth (feet)
Well 24/1-12F1		
Consolidated School Dist. 306. Altitude about 365 feet. Drilled by N. C. Jannsen, 1932.		
Vashon drift:		
Till:		
"Hardpan"	7	7
Puyallup sand:		
Clay, sandy, seep of water at 33 feet	38	45
Sand and gravel, loose	10	55
Clay, sandy	25	80
Sand, loose	1	81
Clay, sandy	24	105
Gravel, coarse, water-bearing	8	113
Clay, sandy	16	129

Casing, 8-inch, set to 129 feet.

Materials	Thickness (feet)	Depth (feet)
Well 24/1-16J2		
P. F. Schmickroth. Altitude about 90 feet. Drilled by N. C. Jannsen, 1935.		
Vashon drift:		
Gravel, loose	1	1
Till:		
Gravel, hard cemented	9	10
Advance outwash and Puyallup sand, undifferentiated:		
Gravel, loose, coarse	46	56
Sand and fine gravel	7	63
Sand, coarse, and fine gravel, water-bearing	17	80

Materials	Thickness (feet)	Depth (feet)
Well 24/1-16L1		
L. M. Lewis. Altitude about 110 feet. Drilled by N. C. Jannsen, 1933.		
Vashon drift:		
Till and outwash:		
Sand and gravel	30	30
Gravel, water-bearing	20	50
Gravel, hard	7	57
Pleistocene deposits, undifferentiated:		
Clay, blue	23	80
"Hardpan", brown	17	97
"Hardpan"	33	130
Sand	15	145
Clay	55	200
Shale(silt?)	90	290

Casing, 8-inch, set to 268 feet; perforated from 26 to 36 feet and 42 to 53 feet.